NASA's

Microgravity Science Laboratory:

Illuminating the Future

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This document was prepared under the auspices of the Marshall Space Flight Center Payload Projects Office by Essex Corporation through a contract to Teledyne Brown Engineering.
Cover Illustration: Kevin Ward
Photo of stove on page 15: courtesy of FiveStar®
Hot spring photo on page 17: copyright C. Blake Powers
Graphic Design: Brien O'Brien, O'Brien Graphic Design

Suggested terms for further research:

acoustic levitation, alloys, combustion, containerless processing, convection, crystals, diffusion coefficient, diffusion flows, electromagnetic levitation, flame(-)balls, flame(s), glasses, IML, International Microgravity Laboratory, ionic metals, laminar combustion, Lewis number(s), Marangoni convection, materials science, materials processing, metallic crystals, metallic liquids, metals, microgravity, overcooling, protein crystallography, proteins, semiconductors, sintering, space-based processing, Spacelab J, Spacelab, Space Station, surface(-)tension(-)driven convection, surface tension, thin films, undercooling, United States Microgravity Laboratory, USML, vapor diffusion

Getting Away To Explore And Build

We often separate ourselves from day-to-day distractions to work more efficiently. Isolation from these events often improves the quality of our work and learning. Scientists, too, often wish to escape the ever-present constraints of Earth's gravity and atmosphere to obtain fresh perspectives on everyday events such as materials processing, heating, and fire safety. Investigators can isolate their experiments on an orbiting spacecraft, where the effects of gravity are almost non-existent. There, in a low-gravity environment, scientists can explore the processes and phenomena behind everyday operations in a way not possible before. Free from the confines of gravity, they can impose precise conditions on experiments to learn more about these phenomena and how they can be controlled.

In many ways, conducting experiments in microgravity can be thought of as taking the cover off a machine to observe its inner workings. Gravity hides many things from investigators: the ways that molten, or liquid, materials solidify; the true structure of complex crystals; and the phenomena that underlie burning (combustion). Microgravity, however, offers scientists a clear view of the processes and conditions that determine the internal structure of a solidifying material and the opportunity to obtain a more even distribution of the ingredients of that material; the chance to grow crystals with almost perfect structures undamaged by the effects of gravity; and a glimpse of the minute forces and occurrences that lie at the heart of a flame.

Free from the effects of gravity, scientists can explore processes in a way not possible on Earth.

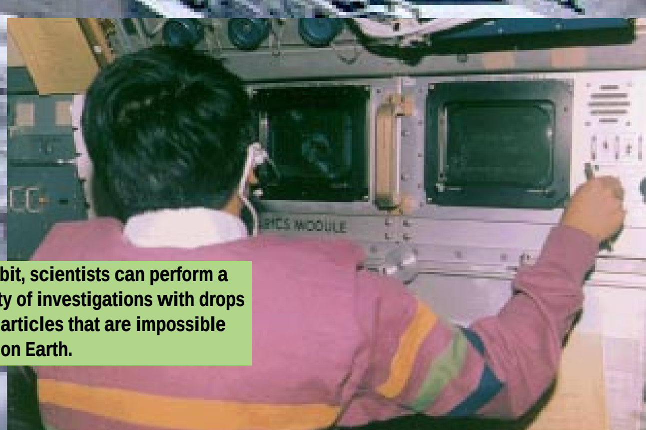
The microgravity environment available in orbit allows scientists to study a variety of biology and biotechnology issues.

For very short periods of time, microgravity can be created on Earth. Experiments can be placed in containers and dropped down tubes or chutes in drop towers to a cushioned landing. These very short periods of microgravity, measured in fractions of seconds to a few seconds, often are sufficient to test theories or equipment designs. The National Aeronautics and Space Administration (NASA) uses drop towers and drop tubes at Lewis Research Center in Ohio and Marshall Space Flight Center in Alabama for these purposes. By flying aircraft in a careful series of roller-coaster-like arcs, brief periods of microgravity — alternating with periods of increased gravity — can be produced. These somewhat longer periods of microgravity, usually 15 to 60 seconds, are suitable for conducting some experiments, for verifying that experiments and hardware will work in microgravity, and for helping train astronauts to work in the absence of gravity. NASA has two planes dedicated to this purpose: a KC-135 weightless training aircraft stationed at Johnson Space Center in Texas and a DC-9 microgravity platform stationed at Lewis Research Center. Sounding rockets, small sub-orbital rockets, launched from NASA's Goddard Space Flight Center Wallops Island facility in Virginia, provide longer periods of microgravity — approximately 4 to 6 minutes. These payloads arch as high as 250 km above Earth's surface before parachuting down to be recovered. The microgravity environment required for long-term investigation and experimentation simply is not available on Earth. Only in space can this unique environment be maintained for the length of time needed by scientists.

Sounding rockets, such as this Black Brant rocket being launched from NASA's Wallops Flight Facility, can provide short periods of microgravity for small payloads.

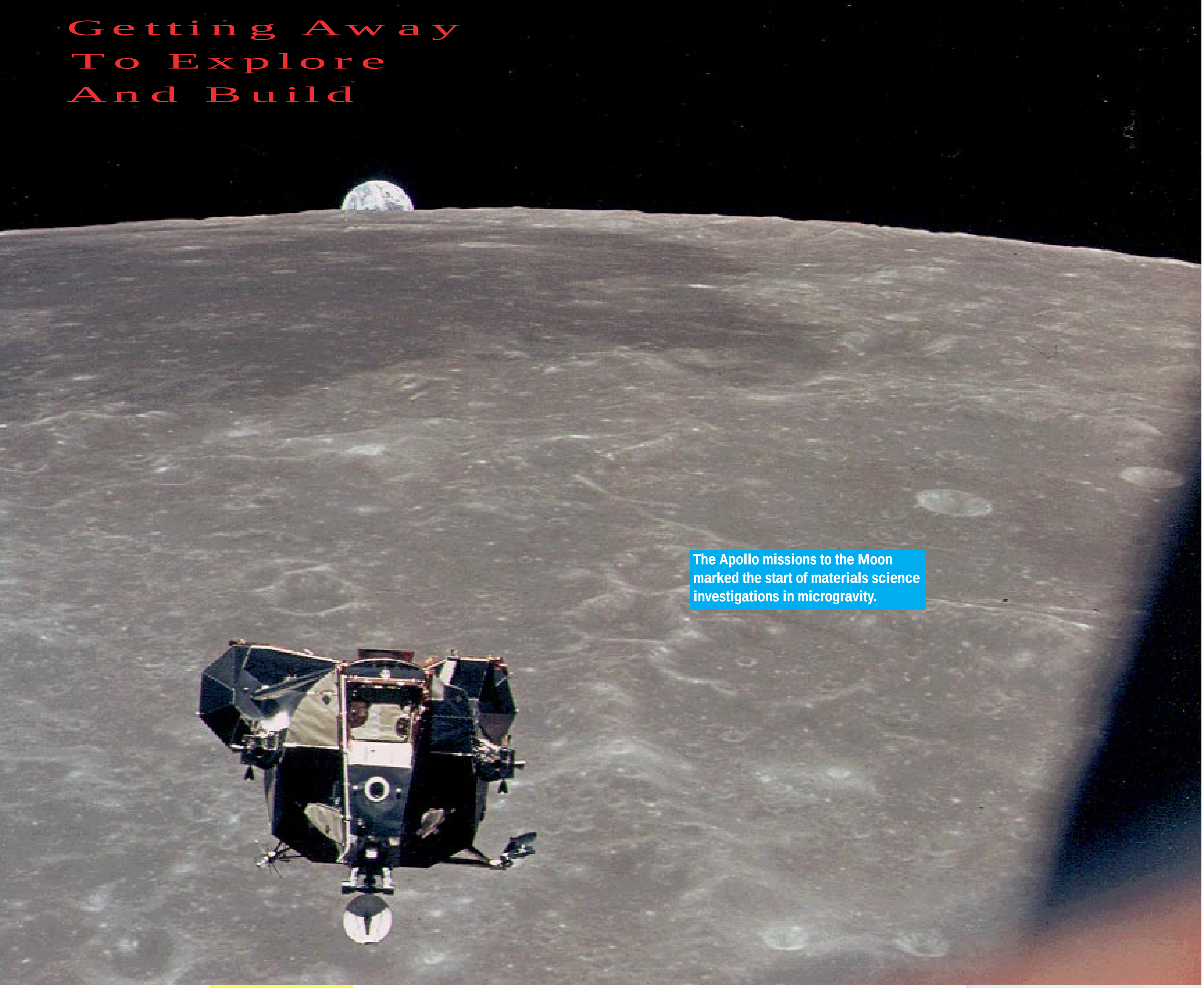
On Earth, drop tubes can provide extremely short periods of microgravity for experimentation.

Brief periods of microgravity, alternating with periods of increased gravity, are created on aircraft flying special trajectories.



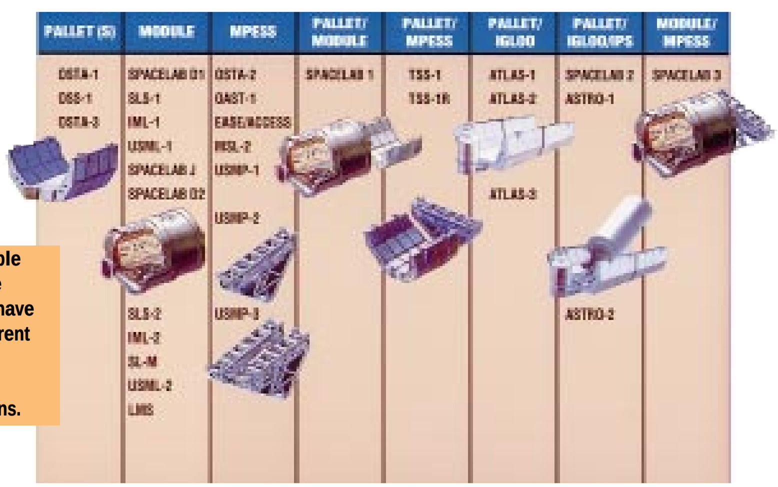
On orbit, scientists can perform a variety of investigations with drops and particles that are impossible to do on Earth.

Getting Away To Explore And Build



The Apollo missions to the Moon marked the start of materials science investigations in microgravity.

The Apollo program provided the first opportunity for extended experimentation in microgravity. The various materials science and life sciences investigations on these flights to and from the Moon laid the groundwork for the first long-term experiments on Skylab, America's first space station.



The interchangeable components of the Spacelab system have been used in different configurations to support more than 25 science missions.

Skylab was an important stepping-stone to modern microgravity sciences. Investigators were able to gather data on changes to the human body that were caused by living in weightlessness for extended periods of time — from 28 to 84 days. They also were able to study the effects of microgravity on other organisms, species ranging from spiders to plants. Experiments in materials science also benefited from these longer periods of microgravity. Samples of metallic crystals, alloys, semiconductors and other materials were produced, and investigators were able to learn much about designing and building specialized hardware for conducting experiments.

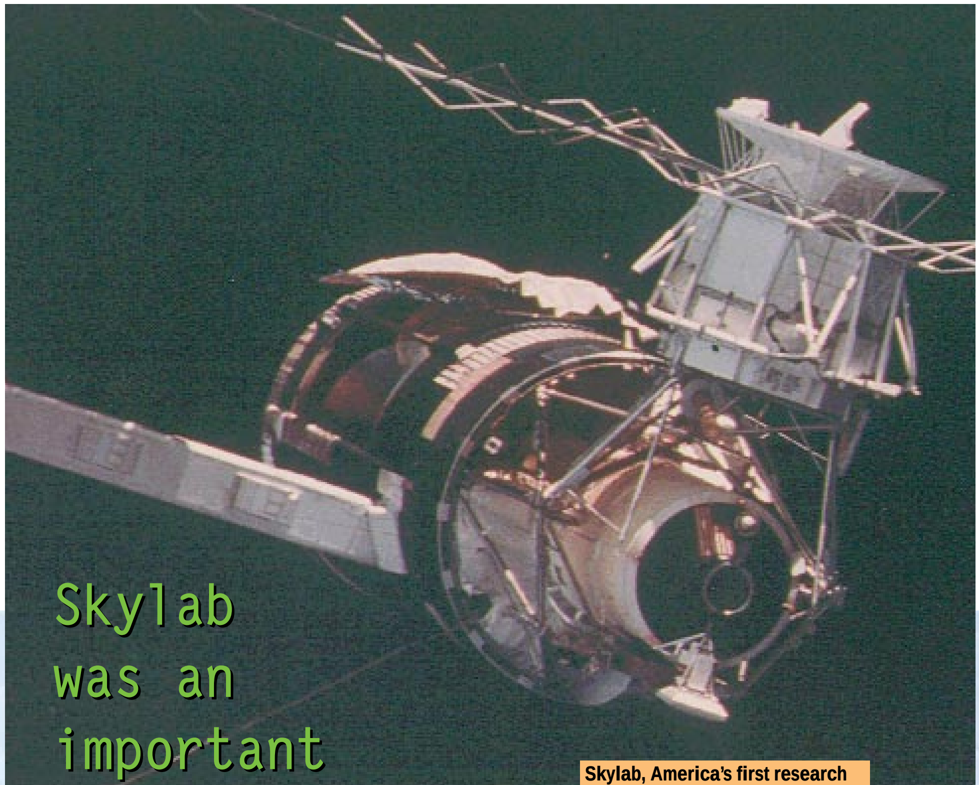
The knowledge gained on Skylab led to the development of new facilities and experiments designed for use on the Space Shuttle, particularly for use in its Spacelab payload.

Spacelab, a joint venture of the European Space Agency (ESA), a consortium of 14 European countries sponsoring space research and technology, and NASA, is the first major international cooperative space effort. It has allowed investigators representing approximately 20 countries to conduct more than 500 experiments in the fields of materials science, life sciences, astrophysics, space technology, and atmospheric and plasma science to be conducted on 30 missions.

Spacelab is a system of interchangeable pressurized laboratory modules, exposed pallets, and complementary structures that fit in the Shuttle's payload bay. The different components can be arranged to provide the best possible laboratory for a given set of experiments. Investigations have been conducted from this outstanding science platform for as long as 16 days, laying the groundwork for operations on Space Station, much the same way the investigations on Skylab formed a basis for Spacelab programs.

Because the International Space Station will be on orbit continuously, it will allow scientists to conduct new experiments for longer periods of time than are possible with Spacelab. From this platform, the opportunities for expanding our knowledge of the Universe and how it works are almost unlimited. Today's Spacelab is providing the bridge needed to develop the more mature microgravity science investigations and hardware that the Space Station will support. Flying on Space Shuttles using the Extended Duration Orbiter package (equipment that allows missions to stay on orbit for up to 3 weeks), Spacelab is providing the opportunity to test Space Station operations and hardware. In addition, the research conducted as part of these operations will provide an extra boost to research planned for Space Station.

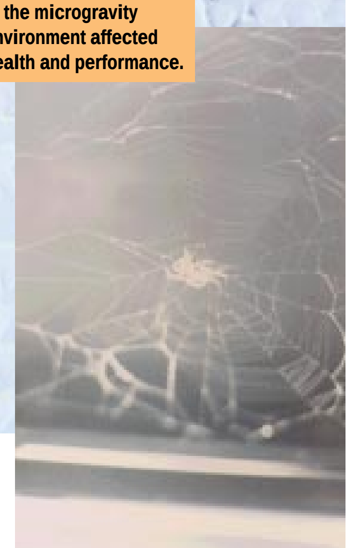
The Space Station will use different hardware than Spacelab in almost every respect. Even the way this hardware will be installed is different. Spacelab equipment is loaded into racks and connected to the various power, data, and supply systems from the rear.



Skylab, America's first research station in space, provided the first opportunity to perform long-term investigations in microgravity.

Skylab was an important stepping-stone to modern microgravity sciences.

The data gathered during Skylab missions on changes to the human body caused by the microgravity environment have provided the foundation for current and future investigations.



Humans were not the only creatures studied to determine how exposure to the microgravity environment affected health and performance.

Getting Away To Explore And Build

Space Station hardware, on the other hand, will be loaded into a new type of rack from the front, and all connections will be made in the front. This makes it easier and more cost effective to upgrade and replace equipment. The new racks, experiment hardware, and procedures need to be tested before the Space Station is built.

The Microgravity Science Laboratory (MSL) is a key component of the bridge between present Spacelab and future Space Station operations. Bringing together many of the major Space Station partners in a joint venture designed to model future operations, MSL builds on the cooperative and scientific foundation of the International Microgravity Laboratory missions (IML-1 and IML-2), the United States Microgravity Laboratory missions (USML-1 and USML-2), Spacelab J, and the German Spacelab missions (D-1 and D-2). It also brings together international academic, industrial, and governmental partners to obtain maximum benefit and results. MSL uses new and existing facilities to expand previous research and begin exploration in new directions. In addition, it is serving as a test-bed for new procedures designed to place scientific payloads into orbit in a shorter amount of time than previously possible.

USML-1

IML-1

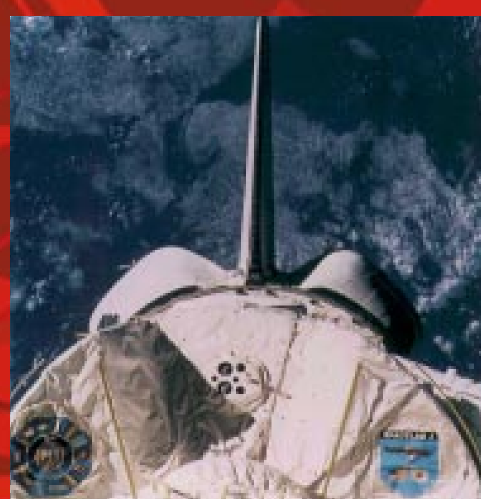
Today's Spacelab is providing the bridge to the Space Station.


D-1

D-2


USML-2


IML-2


SLJ

Doing More In Less

When looking at television images from the Spacelab module or the Space Shuttle, we often see the crew floating around, performing the investigations that lie at the heart of each mission or, in more playful moments, chasing after candy or balls of liquid hanging in mid-air. Often, this apparent weightlessness is incorrectly referred to as "zero-g" or the absence of gravity. More appropriately, the condition experienced by the crew and experiments orbiting Earth is called microgravity. But what is microgravity?

NASA uses the term microgravity to describe a condition of free-fall within a gravitational field in which the weight of an object is significantly reduced compared to its weight at rest on Earth. The effects of gravity are reduced by allowing an object to fall. As it falls, the object and anything in it fall with an acceleration caused almost exclusively by gravity, so they "float" in relation to each other as if there were no gravity. This reduced-gravity environment can be created only by free-fall because, to find microgravity conditions similar to those experienced by astronauts orbiting the Earth, one would have to travel more than 6 million kilometers into space — 17 times farther away than the Moon. At the altitude the Space Shuttle orbits (140 to 250 km), the pull of Earth's gravity is still almost as strong as it is at ground level. If it were possible to drop a ball from the top of a tower that reached to the same altitude at which the orbiter circles Earth, the ball would fall toward Earth just as it would if it were dropped from a tall building. The Shuttle, however, is falling around Earth in such a way that it never hits the ground, allowing its contents and passengers to experience microgravity for as long as the

Often, the crew playfully show the effects of microgravity to viewers on the ground using food, such as this demonstration during the Spacelab J mission by Astronaut Jan Davis.

Shuttle is in orbit. While in free-fall, the Shuttle and its contents are "isolated" from the effects of Earth's gravity. Aboard the orbiter, even the heaviest objects no longer fall "down," and spilled liquids form balls that float rather than form puddles that flow across the floor.

The free-fall environment of the orbiting Space Shuttle provides unique opportunities to researchers. Subtle and complex phenomena, normally hidden by the stronger force of gravity, can be revealed for detailed study. For example, the way a fire starts and spreads can be studied without the interference of gravity, giving scientists a better understanding of the processes involved and, perhaps, leading to improved fire safety. Mixtures that separate on Earth because of the different densities among their components can be mixed evenly and processed in microgravity. This allows scientists to study the processing of such materials and to create advanced materials for study and comparison.

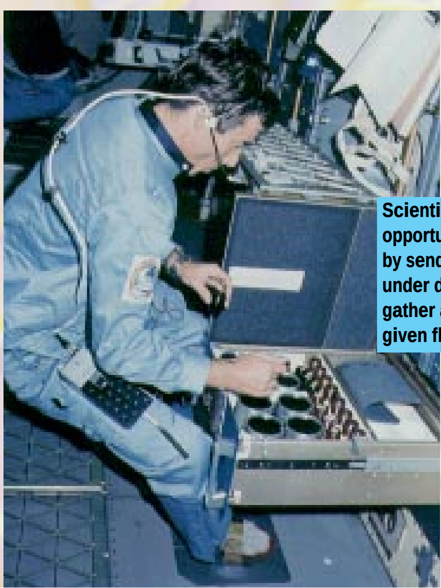
Without the pushing, pulling, and other effects of gravity, more perfect inorganic crystals can be produced, which may eventually lead to the creation of advanced computer chips and semiconductors. The growth of near-perfect protein crystals will enhance our understanding of protein molecular structures and may speed the development of improved drugs. Also, scientists can use the microgravity environment to learn how the presence or absence of gravity affects living organisms. This will aid long-term space efforts and also will provide a better understanding of life on Earth by allowing scientists to study biological processes and phenomena impossible to study in gravity.

While in free-fall, the Shuttle and its contents are "isolated" from the effects of Earth's gravity.

On Earth, gravity can cause some products to pick up imperfections or impurities during processing. In microgravity, scientists can reduce or eliminate many of these problems. Japan's first scientist astronaut in space, Dr. Mamoru Mohri, is observing a sample being processed in a Spacelab module as part of investigations into materials processing in microgravity.

In microgravity, liquids do not spill to the floor or form drops. Instead, they form into balls such as this almost perfectly spherical drink of juice that Dr. Leroy Chiao is preparing to pull into a straw.

To work in microgravity, crewmembers have to use handholds and foot restraints to do even simple operations. For example, if a crewmember were to turn a switch without holding onto something, the crewmember would turn instead of the switch.



Scientists try to make the most of each opportunity to experiment in microgravity by sending up multiple samples, processed under different experiment conditions, to gather as much data as possible on any given flight.

Microgravity in Gravity

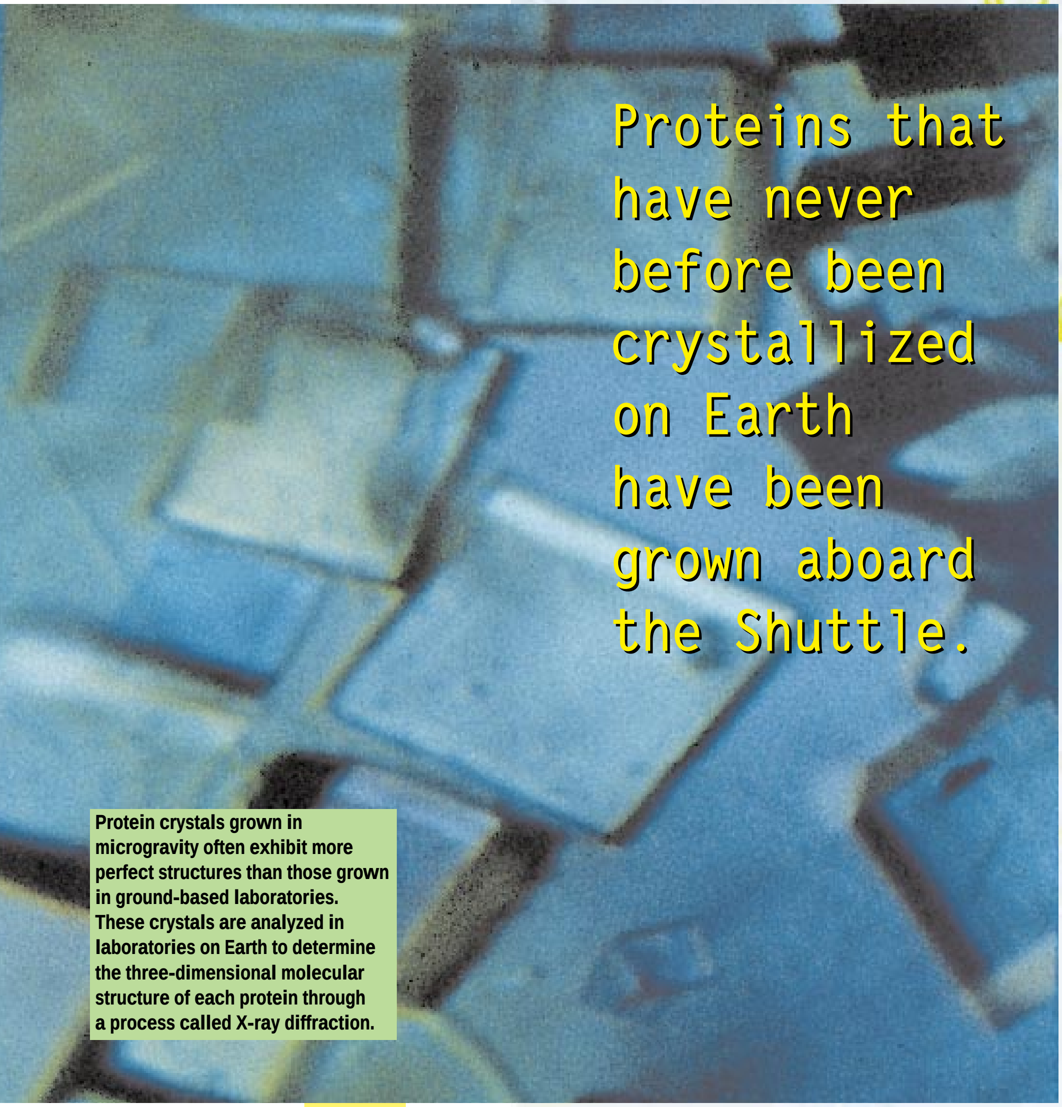
The continuous free-fall experienced by the Shuttle is possible because the orbiter is at the right altitude and speed to cause its “fall” to match the curvature of Earth’s surface. An easy way to visualize what is happening is by doing the same kind of “thought experiment” that Sir Isaac Newton did in 1686.

Newton expanded on his conclusions about gravity, imagining how an artificial satellite could be made to orbit Earth. He envisioned a very tall mountain extending above Earth’s atmosphere so that friction with the air would not be a factor. He then imagined a cannon at the top of that mountain firing cannonballs parallel to the ground. As each cannonball was fired, it was acted upon by two forces. One force, the explosion of the black powder, propelled the cannonball out from the muzzle. If no other force were to act on the cannonball, the shot would travel in a straight line and at a constant velocity. But Newton knew that a second force would act on the cannonball: the presence of gravity would cause the path of the cannonball to bend into an arc ending at Earth’s surface.

Newton described how cannonballs would travel farther from the mountain if the cannon were loaded with more black powder each time it was fired. With each shot, the path would lengthen and soon the cannonballs would disappear over the horizon. Eventually, if a cannonball were fired with enough energy, it would fall entirely around Earth and come back to its starting point. The cannonball would begin to orbit Earth. Provided no force other than gravity interfered with the cannonball’s motion, it would continue circling Earth in that orbit.

The Shuttle can be thought of as the cannonball. It is launched with enough speed and in such a path, known as a *trajectory*, that it constantly falls around Earth. Because the Space Shuttle is in continuous free-fall and upper atmospheric friction is extremely low, a microgravity environment is obtained.

The Structures of Life



Proteins that have never before been crystallized on Earth have been grown aboard the Shuttle.

Protein crystals grown in microgravity often exhibit more perfect structures than those grown in ground-based laboratories. These crystals are analyzed in laboratories on Earth to determine the three-dimensional molecular structure of each protein through a process called X-ray diffraction.

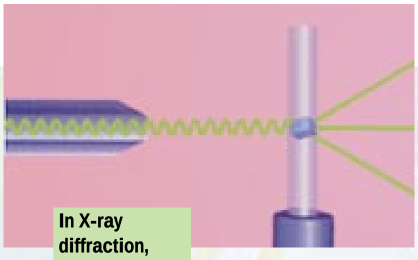
Imagine knowing everything about people or things from the moment you encounter them, including exactly how they will react in any given situation. Doctors would like to have such an understanding about how various diseases, viruses, and drugs will react or work so they can treat a variety of illnesses more effectively. By the same token, farmers and scientists would like this information about viruses and other diseases that affect plants.

While it may never be possible to have such knowledge about human beings, it is possible to develop a better understanding of various diseases through research known as protein crystallography. Proteins are essential components of all living cells and serve many different functions. For example, some proteins make it possible for red blood cells to carry oxygen throughout the body. Other proteins help transmit nerve impulses so we can hear, smell, and feel the world around us, while still others play a crucial role in preventing or causing disease. Proteins are a large group of organic compounds (those that contain carbon) that also usually include atoms of oxygen and hydrogen and may contain sulfur and other elements. Proteins are arranged in one or more chains of amino acids, organic compounds containing nitrogen hydride (NH_2).

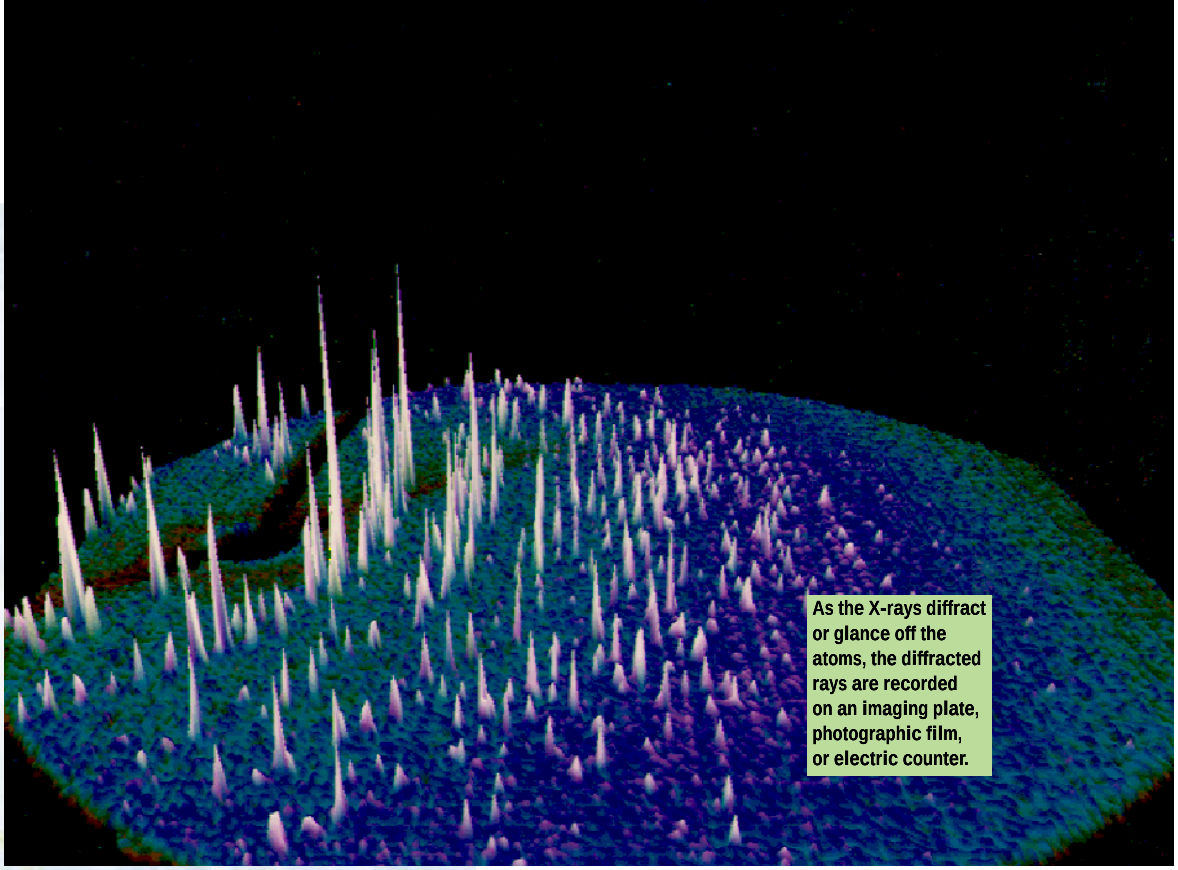
If scientists can decipher the exact structure of a given protein, they can determine how it binds with other proteins to perform its specific function. For example, by knowing the exact structure of a protein involved with digestion, investigators can determine why it is attracted to a specific nutrient and how it breaks that compound apart. By studying a protein that is part of a virus, they can learn how that virus attacks plants or animals.

The difficulty is determining the exact structure of a selected protein. To do this, scientists must grow near-perfect crystals of that protein. These crystals can reveal the three-dimensional molecular structure of a protein, which determines how the protein works.

While some proteins can be crystallized quite easily on Earth, others cannot be because of the force of gravity. Gravity works against the formation of perfect crystals of any substance. By pulling down at the crystal as it forms, gravity distorts the crystal's shape, causes the chemicals that make up the protein to be mixed improperly, and limits the crystal's size. By growing protein crystals in microgravity, investigators can grow near-perfect crystals, which may be larger than those grown on Earth and easier to analyze.



In X-ray diffraction, the crystal is subjected to a beam of X-rays, which are scattered in a regular manner by the atoms in the crystal.

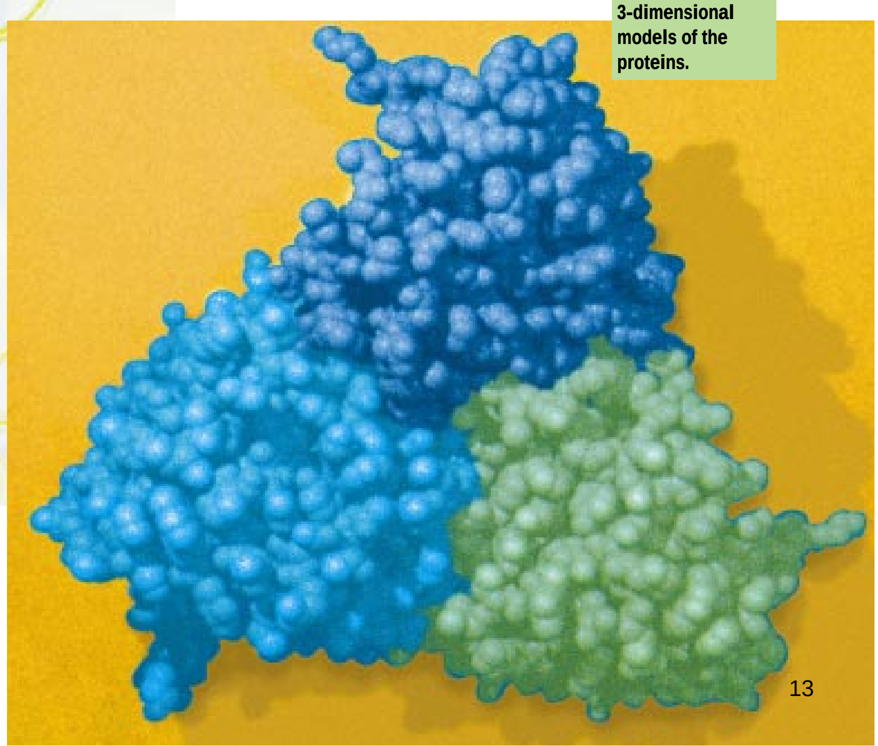


As the X-rays diffract or glance off the atoms, the diffracted rays are recorded on an imaging plate, photographic film, or electric counter.

Many proteins that have never before been crystallized on Earth have been grown aboard the Shuttle. Equally important, scientists have been able to grow different forms of some of these proteins. A good example of this took place on the USML-1 mission when Payload Specialist Dr. Larry DeLucas, a protein crystallographer, was able to grow a particular form of the protein Factor D that he had not been able to obtain during 9 months of ground-based experimentation. This protein is of interest because it can be used in the design of future drugs.

Three protein crystal growth experiments are scheduled for MSL-1. The Protein Crystal Growth Using the Protein Crystallization Apparatus for Microgravity (PCAM) experiment will grow large quantities of various proteins. The Protein Crystal Growth Using the Second Generation Vapor Diffusion Apparatus (VDA-2) experiment will grow high-quality crystals of various proteins using the vapor diffusion method. The Protein Crystal Growth Using the Hand-Held Diffusion Test Cells (HHDTCs) experiment will grow crystals to investigate differences in the processes in microgravity from those on Earth and to refine the cell design of the Observable Protein Crystal Growth Apparatus (OPCGA). Marshall Space Flight Center in Huntsville, Alabama, is NASA's Center of Excellence for protein crystal growth.

Computers perform precise measurements of the intensity of X-rays scattered by each crystal, helping scientists map the probable positions of the atoms within each protein molecule.



From the X-ray diffraction data, scientists can develop computer-generated 3-dimensional models of the proteins.

A Light In The Darkness

We are familiar with combustion, the process of burning; however, we rarely stop to think that burning is a very rapid, often complex, chemical process involving a fuel (the substance that burns or undergoes a chemical change), an oxidizer (a source of oxygen, which is required for combustion to occur), and a source of ignition. When all three components come together in the right manner, a flame is produced. Provided there is a source of ignition, a sufficient supply of oxygen, and a fuel (solid, liquid, or gas), combustion can occur even underwater or in space.

In the simplest terms, combustion occurs whenever oxygen atoms rapidly combine with the atoms of a fuel. A good example of this is the burning of coal, which is made of carbon. With the application of sufficient heat, oxygen atoms in the air combine very rapidly with the carbon atoms in the coal, creating carbon dioxide and releasing large amounts of heat (energy) during the process.

Combustion is, however, rarely this simple and straightforward. For example, coal has elements in addition to carbon that combine with oxygen during burning and produce products other than carbon dioxide.

A vital process that has been the subject of extensive research for more than a century, combustion accounts for approximately 85 percent of the world's energy production — and a significant percentage of the world's atmospheric pollution. Combustion plays a key role in processes involved in ground transportation (the internal combustion engine), spacecraft propulsion (solid rocket motors and liquid fuel engines), aircraft propulsion (jet and internal combustion engines), and hazardous waste disposal (through incineration of the waste).

Despite many years of vigorous study, however, we have only a limited understanding of many fundamental combustion processes, including how pollutants are formed by combustion. Gravity limits studies on Earth by masking many subtle phenomena with buoyancy-induced flows and sedimentation. In the presence of gravity, buoyancy-induced flows are created in fluids (liquids and gases) by heating. When heat is applied to a fluid, the fluid closest to the heat source becomes less dense and is pushed up by the cooler (more dense) fluid surrounding it. As the less dense fluid rises, it is replaced by the more dense fluid, and a flow is created. To control these buoyancy-driven flows during ground-based experimentation, scientists have to limit the size, scale, and duration of their experiments, thus limiting the investigations that can be studied on Earth.

Sedimentation is similar in that materials of different densities separate in the presence of gravity. Fluids of unequal densities separate into layers, with the heavier materials sinking to the bottom. Stirring, levitation, or other measures are required to counteract this separation. These countermeasures also place limits on Earth-based experiments.

In the microgravity environment, buoyancy-driven flows and sedimentation are reduced or eliminated, allowing scientists to expand the scale and duration of experiments and to study processes and phenomena that may be hidden on Earth.

How Do Candles Burn?

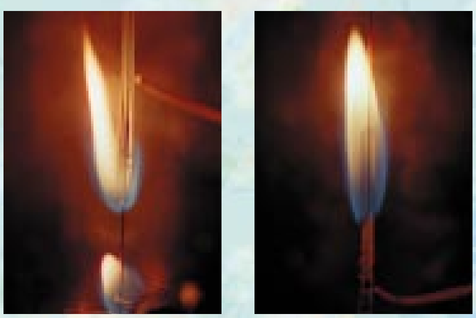
Scientists often use candles to study combustion processes. When candles burn on Earth, the air near the wick heats up, its density decreases, and it rises. Fresh air then is drawn toward the wick, replenishing the oxygen needed for combustion. These air flows are absent in microgravity. As the wick brings fresh fuel to the combustion zone, there are no air currents to bring in fresh oxygen, and product gases like carbon dioxide collect around the wick. As the local oxygen is depleted, combustion slows and the candle is extinguished (or at least burns less vigorously).

A candle flame is a familiar shape on Earth. In microgravity, however, both the shape of the flame and the physical processes involved in burning are different.

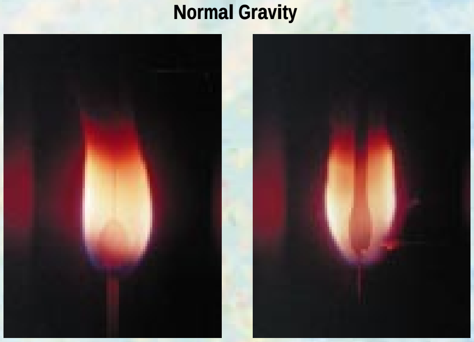
Instead of the familiar tear-drop shape, the shape of a candle flame in microgravity is spherical, just as a drop of water in space is spherical. The flame is smaller because the normal processes that provide oxygen and fuel are almost eliminated.

NASA's combustion science research focuses on six major areas: pre-mixed gas flames, diffusion flames, liquid fuel droplets, fuel dust clouds, the spread of flames along surfaces, and smoldering combustion. The results from experiments in these areas will improve current understanding of how fundamental combustion phenomena are affected by gravity. Also, the results will be used to advance combustion science and technology on Earth and to address issues of fire safety in space. Lewis Research Center in Cleveland, Ohio, is NASA's Center of Excellence for Combustion Science.

The MSL-1 mission will support three combustion investigations. The Laminar Soot Processes investigation will explore soot properties in nonbuoyant laminar jet diffusion flames. The Structure of Flame Balls at Low Lewis-number (SOFBALL) investigation will try to determine if stable, stationary "flame balls" can exist. The Droplet Combustion Experiment will study the processes and phenomena associated with combustion in spherical fuel droplets.



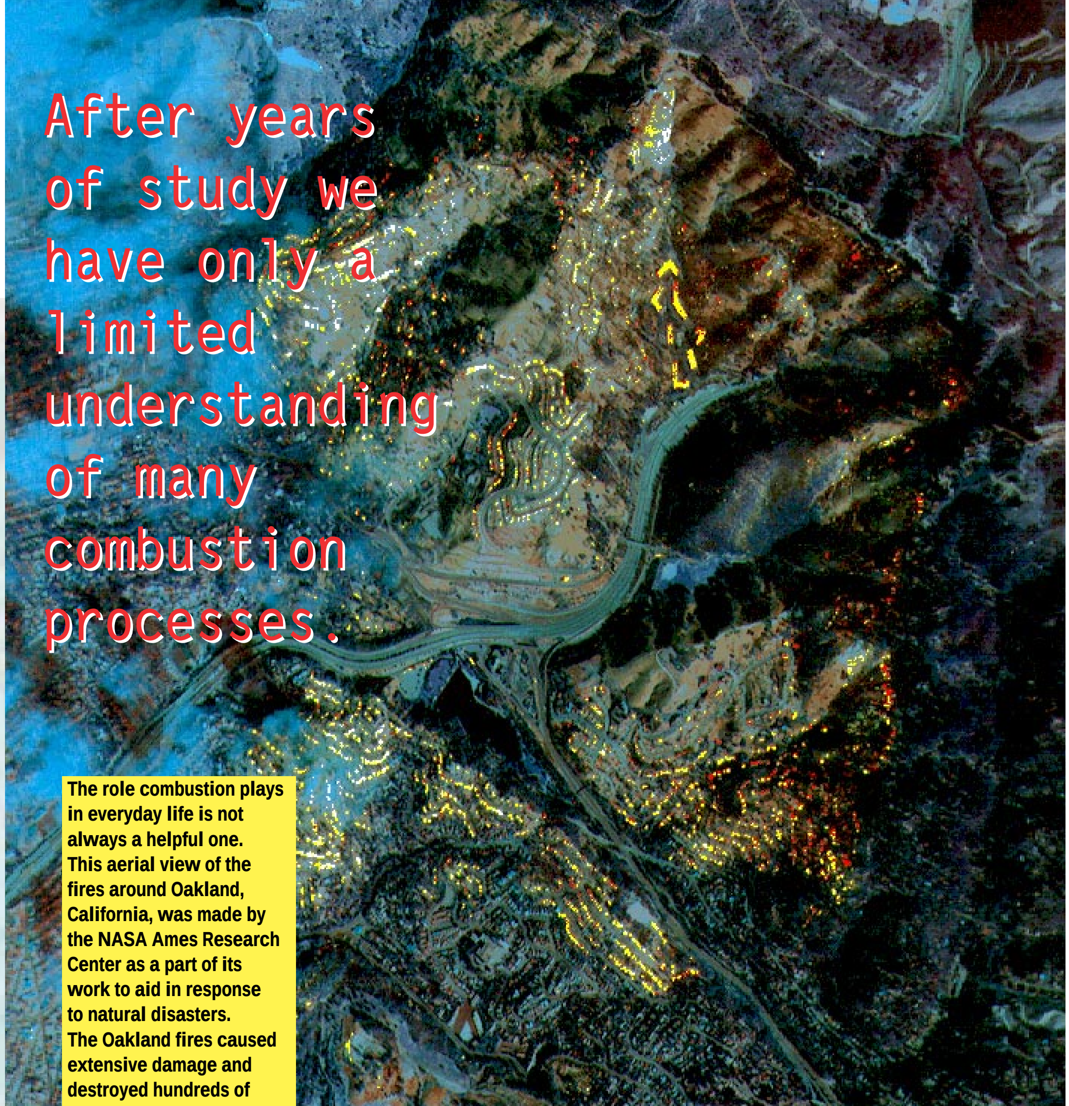
Normal Gravity



Microgravity

Studying combustion in microgravity will help scientists better understand the processes involved, improving both ground-based combustion uses and ground- and spacecraft-fire safety.

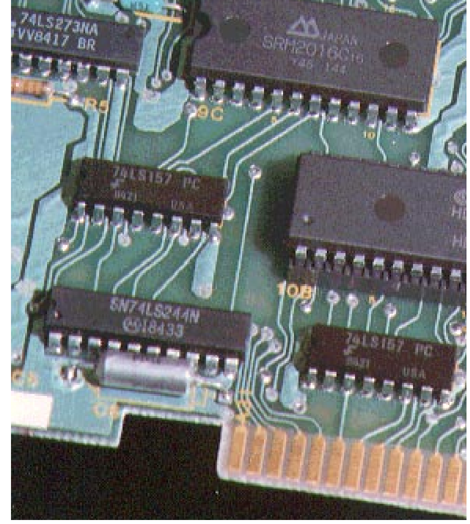
After years of study we have only a limited understanding of many combustion processes.



The role combustion plays in everyday life is not always a helpful one. This aerial view of the fires around Oakland, California, was made by the NASA Ames Research Center as a part of its work to aid in response to natural disasters. The Oakland fires caused extensive damage and destroyed hundreds of homes. The hottest parts of the fire show as white or yellow in this image, with fog — rather than smoke — creating the blue clouds seen to the left of the fires.

Using a burner to heat water or cook food is only one of the many positive ways combustion is used in our lives.

Perfecting Structure and Style

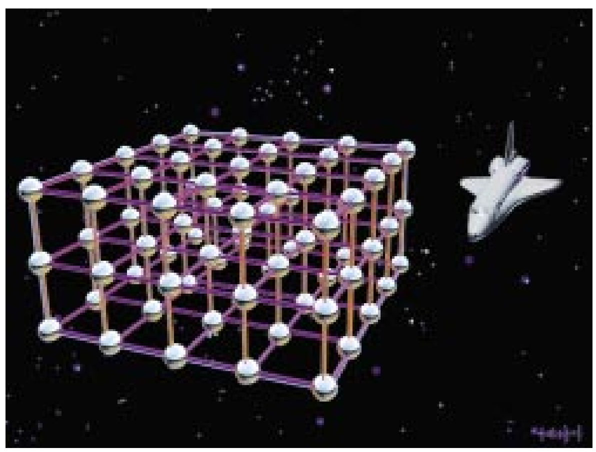


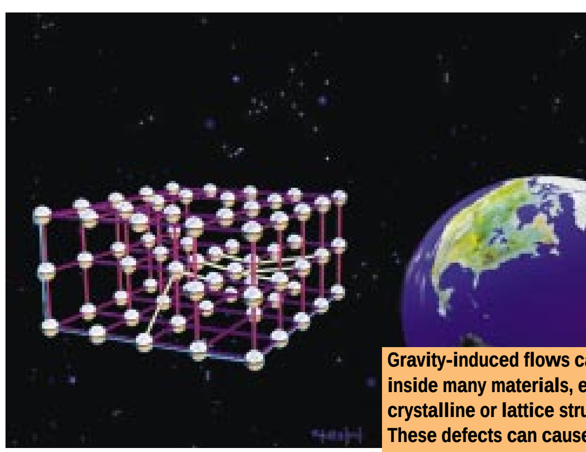
As we go through each day, we may pay little attention to the items we use to do our work, to cook our food, and to communicate with others and even the ones we use for relaxation and play. The tendency is to notice them only when they do not work properly. Yet, most of these items have to be manufactured, making materials science one of the most important fields of scientific research.

The key to materials science research is understanding how the structure of a material forms and how this structure affects the properties of the material. For example, the materials that form "chips" for computers and other electronic devices are crystals. The accuracy of the chip in transmitting electrical impulses, which is paramount to its performing a given task, and its reliability over time depend on the precise alignment of the individual atoms of the material to create a perfect structure.

On Earth, sedimentation and buoyancy cause uneven mixing of the ingredients of the material and can deform the structure as it solidifies. These gravity-induced imperfections limit the usefulness of many electronic materials. Imperfections in the structures of metals and alloys can affect mechanical strength or resistance to corrosion, while similar flaws in glasses and alloys can make them easier to crack or break. Gravity also affects the internal structure of polymers, long chains of organic molecules that form the basis of a range of products from nylon to plastic. Though polymers are not crystals, their long chains of organic molecules often line up with one another — a property known as crystallinity. Controlling this property, and therefore the structure of polymers, could improve a variety of common products and allow polymers to be used in new and important ways.

In microgravity, sedimentation and buoyancy are reduced or eliminated, allowing scientists to study the process of material formation in ways not possible before. Minute forces and phenomena that are overwhelmed by gravity on Earth can be observed and studied. The physical and chemical conditions present during processing can be controlled carefully and can be changed, enabling investigators to learn how these factors affect the final structure of the material. The knowledge gained from these studies will help future microgravity research and material processing efforts and also will be used to improve materials processing on Earth. Marshall Space Flight Center in Huntsville, Alabama, is NASA's Center of Excellence for Materials Science.





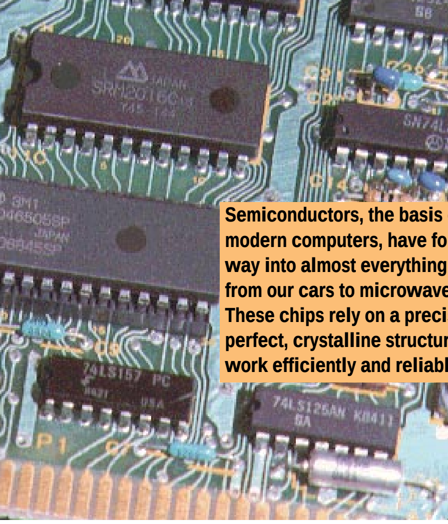
Gravity-induced flows can cause defects inside many materials, especially those with crystalline or lattice structures (bottom). These defects can cause structural weakness or prevent electricity from being transmitted efficiently. They also limit what can be learned about the structure and function of various crystals. Processing in microgravity can result in nearly perfect internal structure (top).

The Four States of Matter

On Earth and in space, matter exists in one of four basic states: solid, liquid, gas, or plasma. We deal with each of these every day. Solid objects form the world around us, from the ground we walk on to the components of televisions and other electronic devices we use for communication and entertainment. Liquids, such as water, make life possible. Gases form the air we breathe and the wind that cools us on a summer day. Plasma, gases whose atoms have lost one or more electrons (becoming ionized) to create a cloud of charged particles, is contained in the long glass tubes of fluorescent lights that provide much of the light in our schools and workplaces.

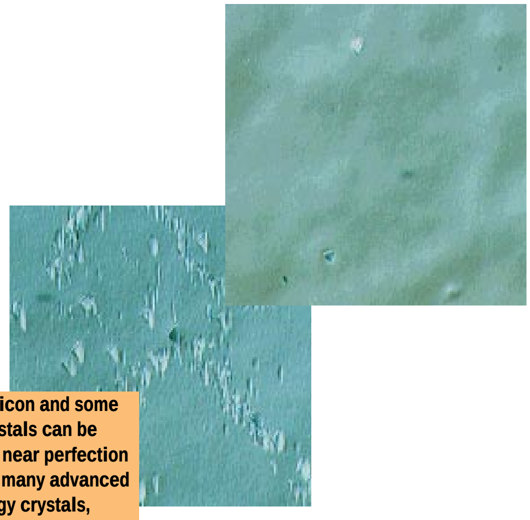
Matter regularly changes between these states. Water provides an excellent demonstration of this transition. Under typical conditions, water is a liquid and flows through a series of pipes to come out of the tap in a sink. If water is cooled sufficiently, the atoms in it no longer move as fast, and it becomes a solid — ice. If water is heated, it gradually turns into a vapor — steam. If steam is heated sufficiently, it will turn into a plasma when the vaporized water molecules break apart into electrons and ions.

Though there are four states of matter, materials scientists are primarily concerned with two forms of matter: solid and fluid. These are referred to as "forms" because each is composed of one of two types of structures. All solids have either a crystalline or non-crystalline internal structure. Fluids are either liquids or gases but share the common trait that they flow, or move, in response to an outside force such as gravity. Materials processing, and therefore materials science, often changes materials from solids to fluids and back again. The change between forms is a crucial part of materials processing. Understanding the events and changes that occur during these times and how these changes affect properties of materials is an important focus of materials science research.



Semiconductors, the basis of all modern computers, have found their way into almost everything we use, from our cars to microwave ovens. These chips rely on a precise, near-perfect, crystalline structure to work efficiently and reliably.

MSL-1 will feature 19 materials science investigations in 4 major facilities. These facilities are the Large Isothermal Furnace, the EXPRESS Rack, the Electromagnetic Containerless Processing Facility (TEMPUS), and the Coarsening in Solid-Liquid Mixtures (CSLM) facility. Additional technology demonstrations and experiments will be performed in the Middeck Glovebox.



While silicon and some other crystals can be grown to near perfection on Earth, many advanced technology crystals, such as cadmium zinc telluride, have numerous imperfections, as seen in the lower photomicrograph of a typical Earth-grown crystal. Experimentation in microgravity reduced these imperfections by three orders of magnitude, as shown in the upper photomicrograph of a sample grown on the USML-1 mission.

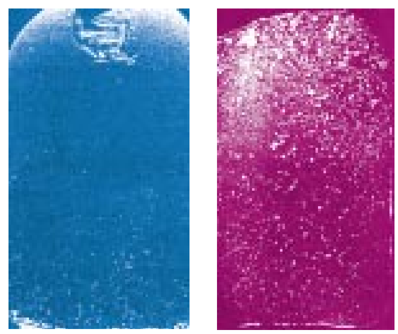
The Fluid Form

Everyone has practical experience with fluids (liquids and gases), and we know intuitively how a fluid will behave under normal circumstances. Steam rises from the surface of a hot spring or a boiling pot, and water spilled on a tabletop runs over, and even off, the surface. Gravity is intricately involved with many of the aspects of fluid behavior on Earth.

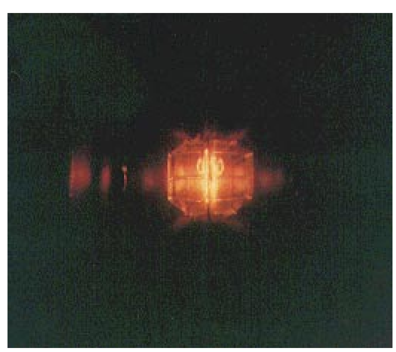
Many of our intuitive expectations about fluids do not hold up in microgravity because the effects of other forces, such as surface tension, control fluid behavior when the influence of gravity is removed. The spherical drops of liquid that form when an astronaut spills water is a familiar example of this phenomena. In microgravity, surface tension on the drops produces almost perfect spheres, while on Earth, gravity distorts them into teardrop shapes.

Differences in fluid behavior on Earth and in microgravity often present engineers and astronauts with practical problems. For example, tanks that contain fluids, such as propellants, must be pressurized so that fluids will flow from the tanks and through pipes. These technical challenges are created by the same phenomena that offer scientists unique opportunities to explore different aspects of fluid physics.

Not only is the knowledge of fluid behavior gained in space important to basic science, but it is also a key to new technologies. The behavior of fluids is at the heart of many phenomena in materials processing, biotechnology, and combustion science. Surface-tension-driven flows, for example, affect semiconductor crystal growth, welding, and the spread of flames on liquids. The dynamics of liquid drops are an important aspect of chemical process technologies and of meteorology. Research conducted in microgravity, such as that being conducted on MSL, will increase our understanding of fluid physics and provide a foundation for predicting, controlling, and improving a vast range of technological processes.



In microgravity, heavier particles are no longer pulled “down” to the bottom of a container, allowing a more even mixing of ingredients as shown in these photographs of an Earth-processed sample (left) and the same mixture processed in microgravity (right).



A sample of glass is melted in a test of acoustic levitation conducted during the brief period of microgravity available during parabolic flight of an aircraft. In microgravity, less force is needed to levitate and control the sample, and processing can continue for long periods of time.

The Solid Form

Just as fluids can be subdivided into liquids and gases, solids can be subdivided into crystalline or non-crystalline (amorphous) forms, based on the internal arrangement of their atoms or molecules.

The most common form of solid is the crystalline form.

The crystalline form includes minerals, such as geodes or quartz crystals; metals, including steel, iron, or lead; ceramics, such as a dinner plate or floor tile; and semiconductors, which are used in televisions or radios. Crystalline solids have a repeating, three-dimensional pattern to their internal structure: the atoms line up on planes that are stacked upon each other.

Crystals typically have different regions, where the planes are lined up in different directions. This is known as a polycrystalline structure, and the individual regions are known as grains. The size and orientation of these grains help determine the strength of a metal or the brittleness of a ceramic. Some materials, such as semiconductors, can benefit from the elimination of all grains but one, producing a single crystal with the constituent atoms lining up on a single set of geometric planes.

Crystals can form in many ways: they can result from freezing liquids, the way ice cubes form; they can precipitate from solution, the way rock candy is made from a sugar solution; or they can condense from vapor, the way frost forms in a freezer. In all of these cases, gravity affects how the crystals grow. By conducting experiments on crystal growth in microgravity, scientists can learn how gravity influences these processes and how crystals grown in microgravity differ from those grown on Earth.

A Bridge To The Future

Space Station: Instead of mere seconds, minutes, or hours in microgravity, investigations on this orbiting platform will have days, weeks, or months of time in this unique environment. Long-term experimentation will be enhanced by onboard analysis, eliminating the need to return samples to Earth, a process which may damage subtle and fragile structures. An X-ray crystallography facility, for example, will allow protein crystals to be analyzed on orbit, at the optimum point in their growth process.

The unparalleled opportunities offered by this orbiting science platform will enhance our understanding of the Universe, while providing information that has down-to-Earth applications. Making the most of this opportunity, however, requires a bridge connecting the foundations that have been laid by Apollo, Skylab, and previous Spacelab missions and the next spacecraft of possibility: Space Station.

The Microgravity Science Laboratory program helps span the gap between what is and what will be. Using Spacelab as a literal transition vehicle, MSL provides the means to test some of the hardware, facilities, and

Opportunities offered by an orbiting science platform will enhance our understanding of the Universe.

procedures that will be used on Space Station. Almost everything about Space Station will be different from past efforts, from how experiments are developed to the way they will be installed. While ground-based testing and development can help with portions of this process, the best and most cost-effective way to prepare is to try each part of the process during an actual spaceflight.

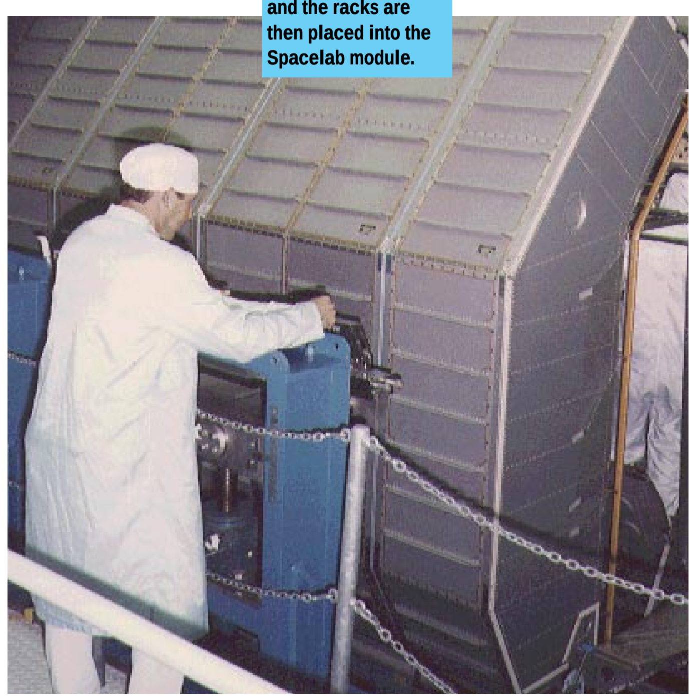
Spacelab is a very capable platform that provides unparalleled flexibility to investigators because its hardware can be modified or matched to the needs of the experiment. This flexibility, however, results in a relatively lengthy, and sometimes complex, process for combining experiment and facility hardware with the Spacelab and orbiter systems. In contrast, Space Station will challenge investigators to provide experiments that will mate with existing hardware and work within preset resource limits. Also, the time for identifying an experiment and placing it in orbit will change. NASA has reduced the time required for getting selected investigations to orbit from approximately 2 years to 9 months.

Obviously, this new way of integrating investigations and equipment will require new procedures at every step. MSL is providing a real-time test of this new way of performing experiments in space, helping to validate and improve the process.

A key component of these operations is the EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Rack, which is designed for quick and easy installation of experiment and facility hardware on orbit. While hardware and facilities are integrated into Spacelab racks from the back before the racks are installed in the Spacelab module, Space Station experiments will be placed into EXPRESS Racks from the front. External cables and tubing will then be used to connect the experiment hardware to power, water, and other Space Station resources.

On the first MSL mission, the EXPRESS Rack will take the place of a Spacelab double rack, and special hardware will provide the same structural and resource connections the rack will have on Space Station. During the mission, two payloads will be flown to

When completed, the International Space Station will provide an unparalleled base for a variety of scientific investigations.



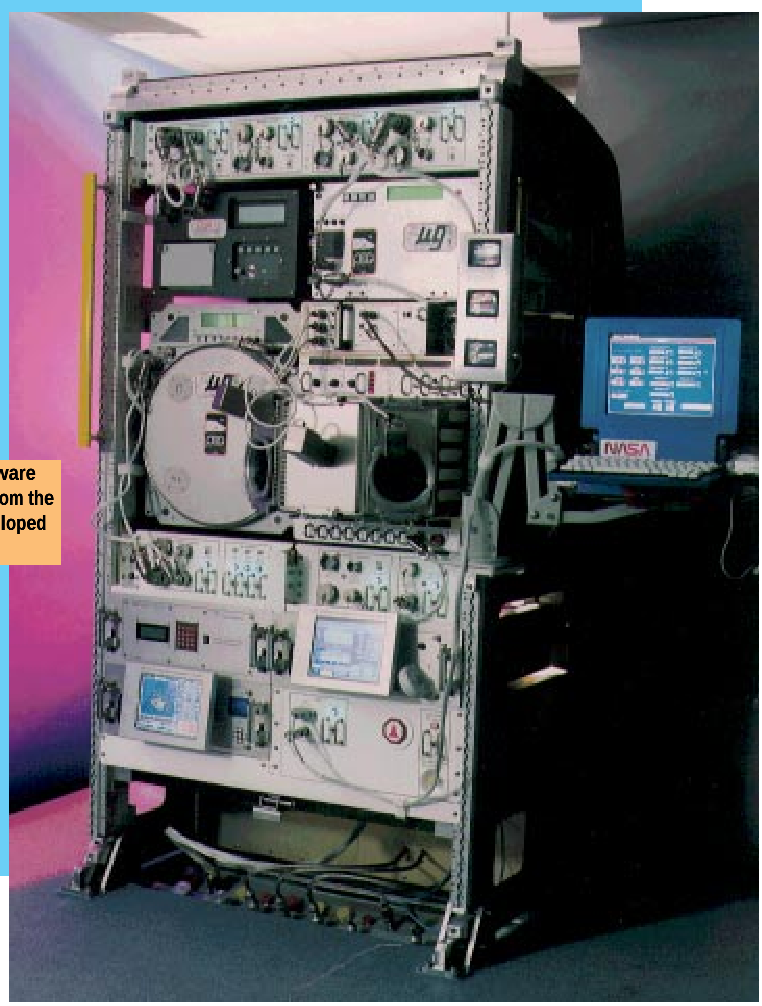
On Spacelab, experiment hardware is loaded into racks, all connections are made in the back, and the racks are then placed into the Spacelab module.

check the design of the EXPRESS Rack hardware and to verify the development and integration processes. To help validate the system, the Physics of Hard Spheres (PHaSE) experiment will require the equivalent of four Spacelab middeck lockers and a Standard Interface Rack drawer. It will use the majority of EXPRESS Rack resources, including power, data, and cooling water. Selection of the second investigation, the Astro/Plant Generic Bioprocessing Apparatus experiment, was postponed until a year before launch to help test the short integration cycle planned for Space Station.

MSL also will refine the use of remote sites for science operations and support. Remote operations have been used on previous Spacelab missions, and remote operations on MSL will make use of previous hardware and facilities. This mission, however, also will involve a new remote operations site in Japan.

Another advanced operational concept being tested on MSL is the use of “expert” software systems. These systems, which are expected to reduce the number of people required to support Space Station operations, are software packages designed to augment human controllers and provide a rapid response to changes in operations. For example, a software package is being developed to assist the Payload Systems Engineer by gathering data about the unique aspects of each payload or experiment. With this data, the system will be able to supply immediate information about impacts to the operation of each experiment should there be an unscheduled occurrence, such as a change in available resources (electrical power, cooling, etc.) or a need to start or stop an experiment.

By thoroughly testing each of these new procedures, hardware, and systems, MSL is helping ensure that Space Station research has the best start possible. In addition, data and samples from the scientific investigations will provide information needed to ensure mature, long-term research in microgravity.



Because experiments and hardware will be loaded and connected from the front, a new rack has been developed and will be tested on MSL.